Future Climate Projections for Annual and Seasonal Rainfall in Sri Lanka using CMIP5 Models
Thanuja Darshika, Shiromani Jayawardane

Department of Meteorology, Sri Lanka

Abstract:
Statistically downscaled data into 25kmx25km grid resolution of 6 earth system models under coupled model inter-comparison project 5 (CMIP5) are analyzed to see the future Changes in annual as well as seasonal Rainfall over Sri Lanka for 3 time periods; 2020–2040, 2040-2060 and 2070-2090 relative to baseline climatology period 1975-2005 for two emission scenarios; Rcp4.5 representing low emission and Rcp8.5 representing high emission scenario. The results of Rainfall changes are indicated that

- Annual rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts for the period 2020-2040 and positive and increasing there after under RCP 4.5 scenario. Annual rainfall anomaly is positive and increasing for all 3 time periods under RCP 8.5 scenario.
- Southwest monsoon rainfall anomaly is positive and increasing in both RCP 4.5 and RCP 8.5 scenarios with significant increase in rainfall over the wet zone.
- Northeast monsoon rainfall anomaly negative and negative trend is observed in RCP 4.5 and RCP 8.5. Decrease in rainfall is significant in the dry zone.
- First Inter Monsoon rainfall anomaly is negative in 2020-2040, slightly negative in 2040-2060 and positive except Northeastern parts under RCP 4.5. First Inter Monsoon rainfall anomaly is negative in all 3 time periods under RCP 8.5 scenarios. No significant trend is evident in RCP 8.5.
- Second Inter Monsoon rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts in 2020-2040 and positive and increasing after that under RCP 4.5. Second Inter Monsoon rainfall anomaly is positive and increasing in 8.5 scenarios with increase in rainfall is significant in the Southwestern and Southeastern parts.

Introduction
Climate models are currently the most credible tools for making projections of future climate over the next 100 yr. A range of different climate models exist, from the simplest energy balance models to the most sophisticated global circulation models (GCMs; see, for example, McGuffie and Henderson-Sellers, 2004). Uncertainty in climate change projections include representation of the GHG emissions scenarios, uncertainties associated with future estimates of population growth, changes in land use, and the economic growth etc. Further uncertainties in climate modeling arise from uncertainties in initial conditions, boundary conditions, observational uncertainties, uncertainties in model parameters and structural uncertainties resulting from the fact that some processes in the climate system are not fully understood or are impossible to resolve due to computational constraints (IPCC, AR4).

The Intergovernmental Panel on Climate Change (IPCC) Fourth assessment report (AR4) stated that the current understanding of future climate change in the monsoon regions remains one of considerable uncertainty with respect to circulation and precipitation (IPCC AR4 Sections 3.7, 8.4.10 and 10.3.5.2).

Multi-model ensembles are defined in these studies as a set of model simulations from structurally different models, where one or more initial condition ensembles are available from each model and it is identified that projections have higher reliability and consistency when several independent models are combined (Doblas-
Reyes et al. 2003; Yun et al. 2003). Multi-model projections for long-term climate change were used in reports of the Intergovernmental Panel on Climate Change (IPCC), where unweighted multi-model means rather than individual model results were often presented as best guess projections (IPCC 2001).

According to previous studies, an increase in precipitation is projected in the Asian monsoon (along with an increase in interannual season-averaged precipitation variability) and the southern part of the west African monsoon with some decrease in the Sahel in northern summer, as well as an increase in the Australian monsoon in southern summer in a warmer climate. Differently from precipitation, Asian monsoon circulation was projected to decrease by 15 % (Tanaka et al. 2005; Ueda et al. 2006).

The main objective of this paper is to develop CMIP5-based short-term (2030s representing climatology over 2021–2040), medium-term (2050s representing climatology over 2041–2060) and long-term (2080s representing climatology over 2071–2090) climate change projections in Rainfall for Sri Lanka based on a multi-model ensemble of 6 models.

The remainder of the paper is organized as follows. Descriptions of the data and analysis method used are presented in section 2. In section 3, Future climate projections for annual and seasonal rainfall in Sri Lanka using CMIP5 models are investigated. Conclusion is presented in section 4.

Data and Methodology

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the CMIP5 and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5.

Table 1: Earth System models used to evaluate

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
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<tbody>
<tr>
<td>CanESM2</td>
<td>The Second Generation Coupled Global Climate Model</td>
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<tr>
<td></td>
<td>Canadian Centre for Climate Modelling and Analysis (2.8*2.8)</td>
</tr>
<tr>
<td>CNRM-CM5</td>
<td>National Centre for Meteorological Research/ Meteo-France (1.4 * 1.4)</td>
</tr>
<tr>
<td>CSIRO-MK3-6-0</td>
<td>Commonwealth Scientific and Industrial Research Organization (CSIRO) and the</td>
</tr>
<tr>
<td></td>
<td>Queensland Climate Change Centre of Excellence (QCCCE). (1.895*1.875)</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>Geophysical Fluid Dynamic Laboratory NOAA, USA Coupled Climate Model (2 * 2.5)</td>
</tr>
<tr>
<td>MRI-CGCM3</td>
<td>Global Climate Model of the Meteorological Research Institute, Japan (1.132*1.125)</td>
</tr>
<tr>
<td>NCAR-CCSM4</td>
<td>National Center for Atmospheric Research, USA Coupled Climate Model (0.942 * 1.25)</td>
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Based on the model performance of historical runs NASA Earth Exchange Global Daily Downscaled Projections of 6 GCM models (CanESM2, CNRM-CM5, CSIRO-MK3-6-0, GFDL-CM3, MRI-CGCM3 and NCAR-CCSM4) with 25km grid spacing were used future projections for Sri Lanka (Herath 2016). Future change of precipitation for 3 time periods 20-year centered on 2030s, 2050s and 2080s (2020-2040, 2040-
2060 and 2070-2090) for 2 emission scenarios RCP 4.5 and RCP 8.5 were constructed by comparing climatological means during the historical run period (1975–2005). Spatial patterns of precipitation for all three futures are discussed on Seasonal and annual basis. Never the less this work is giving good initial idea about the future climate changes in precipitation over Sri Lanka.

**Results**

Three time slices incorporating 20-year centered on 2030s, 2050s and 2080s were examined to gain some insight into the range of future prediction of temperature and precipitation for Rcp8.5 and Rcp4.5 scenarios. Spatial patterns of precipitation and temperature for all three futures are discussed on Seasonal and annual basis. Never the less this work is giving good initial idea about the future climate changes in temperature and precipitation over Sri Lanka.

![Multi model ensemble of change in Southwest Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).](image)

For the period from 2020 to 2040 positive anomaly rainfall is predicted over most parts of the island by multi-model ensemble prediction under low and high (Figure. 1) emission scenarios.

For the period from 2040 to 2060, and 2070 to 2090 positive anomaly rainfall is predicted over most parts of the island by multi-model ensemble prediction under low and high (Figure.1) emission scenarios. Higher positive values are clearly apparent in the wet zone. It is evident that the intensity as well as areal extension of the positive rainfall anomaly over the wet zone increases with time (Figure. 1).
Figure 2: Multi model ensemble of change in Northeast Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

For Northeast monsoon season, the multi-model ensemble product predicted negative anomaly over the entire island under low emission scenario and slightly positive anomaly over the most parts of the island under high emission scenario for 2020-2040 period (Figure 2).

For the period from 2040 to 2060, multi-model ensemble product predicted negative rainfall anomaly over the most parts of Sri Lanka for both low and high emission scenarios (Figure 2).

For the period from 2070 to 2090, multi-model ensemble product predicted negative rainfall anomaly over Sri Lanka for both low and high emission scenarios with more negative values can be seen dry zone (Figure 2).

Figure 3: Multi model ensemble of change in First Inter-Monsoon Rainfall, relative to 1975-2005 for low emission scenario (RCP 4.5) (upper) and high emission scenario (RCP 8.5) for time periods (2020-2040), (2040-2060), (2070-2090).

When consider about the First inter monsoon season (Figure 3), negative rainfall anomaly is evident in 2020-2040 period, slightly negative rainfall anomaly is evident in 2040-2060 period and positive rainfall anomaly is evident in 2070-2090 period according to the medium emission scenario. But according to the results of the high emission scenario it shows negative anomaly rainfall in 2020-2040, 2040-2060 and 2070-2090.
For second inter monsoon season, the multi-model ensemble product predicted negative anomaly over the northeastern parts while slightly positive anomaly elsewhere (Figure 4) for low emission scenario for 2020-2040 period. For high emission scenario, the multi-model ensemble product predicted positive anomaly rainfall over most parts of the island (Figure 4) for 2020-2040 period.

For the period from 2040 to 2060, the multi-model ensemble product predicted positive rainfall anomaly over Sri Lanka for both low and high emission scenarios (Figure 4).

The multi-model ensemble prediction predicted positive rainfall anomaly over the entire country for 2070-2090 period under low and high emission scenario (Figure 4).

The multi-model ensemble product indicated negative anomaly over the dry zone and positive anomaly over the dry zone for 2020-2040 period under low emission scenario. Multi-model ensemble predicted positive anomaly over most parts of the island for 2020-2040 period under high emission scenario (Figure 5). Increasing rainfall is significant over the wet zone in most models.
The multi-model ensemble product indicated positive rainfall anomaly over the entire country for 2040-2060 period under both low and high emission scenarios with significant increase in rainfall over the wet zone.

The multi-model ensemble product indicated positive rainfall anomaly over the entire country for 2070-2090 period under both low and high emission scenarios with significant increase in rainfall over the wet zone. Increase in rainfall over the wet zone is more significant in high emission scenario than high emission scenario.

The nonlinear and chaotic nature of the climate system imposes natural limits on the extent to which skilful predictions of climate statistics may be made. Model-based ‘predictability’ studies, which probe these limits and investigate the physical mechanisms involved, support the potential for the skilful prediction of annual to decadal average temperature and, to a lesser extent precipitation (IPCC, AR5 Synthesis report). Even though the Near-term (2020-2040) climate projections are important to decision makers in government and industry, the uncertainty during this period is high due to the climate is more reliance on the initial state of internal variability and less reliance on external forcing from emission scenarios.

**Conclusion**

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) data GCM 6 climate models (25-kilometer (km) grid resolution) were compared with model historical runs and observed data from 1975-2005 to evaluate model performance. NEX-GDDP downscaled models were captured the bi-modal pattern of annual cycle of precipitation in Sri Lanka as well as the spatial pattern of precipitation of annual average as well as seasonal average.

NEX-GDDP data of GCM 6 climate models were used to develop figures climate projections.

The Representative Concentrated Pathways (RCP) RCP 8.5 and 4.5 scenarios from the IPCC AR5 2013, representing high and medium futures, respectively, were adopted, with three time periods—2030s, 2050s, and 2080s.

The results indicated that the Annual rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts in 2020-2040, while Annual rainfall anomaly is positive and increasing thereafter under low emission scenario RCP 4.5.

Southwest monsoon rainfall anomaly is positive and increasing in both low (RCP 4.5) and high (RCP 8.5) emission scenario.

Northeast monsoon rainfall anomaly is negative for short term, medium term and long term projections observed under low emission scenario RCP 4.5.

Northeast monsoon rainfall anomaly slightly positive in short term term projection 2020-2040, and negative thereafter for medium term and long term projections under high emission scenario.

First Inter Monsoon rainfall anomaly is negative in 2020-2040, slightly negative in 2040-2060 and positive except Northeastern parts under low emission scenario RCP 4.5.

First Inter Monsoon rainfall anomaly is negative in all 3 time frames with no significant trend under high emission scenario 8.5.

Second Inter Monsoon rainfall anomaly is negative in in Northeastern parts, and positive in Southwestern parts in 2020-2040. Positive and increasing after that under RCP 4.5.
Second Inter Monsoon rainfall anomaly is positive and increasing in 8.5 scenarios with significant increase of positive rainfall anomaly over the Southwestern and Southeastern parts.

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References